MANUAL OF INSTRUCTION

FOR

LOCOMOTIVE ENGINEERS

AND

FIREMEN.

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A MANUAL OF INSTRUCTION

FOR THE

ECONOMICAL MANAGEMENT

OF

LOCOMOTIVES,

FOR

LOCOMOTIVE ENGINEERS AND FIREMEN.

BY

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INTRODUCTION.

As the possible success of operating and maintaining the property of a railway with any advantage to the company which owns it depends upon the care and economy with which each of its several departments are operated, so the successful and economical operating of any department depends upon the good judgment, and careful economy, which all who serve in that department exercise in the performance of their respective duties.

The cost of supplies for engines, fuel, oil, etc., repairs, and wages, forms the bulk of the operating expenses of the locomotive department, which amounts to immense sums of money each month, and which reduce, just so much, the profits of the company.

The cost of supplies depends, of course, upon the quantities used, which in turn depend upon conditions of service, such as the number and weight of cars pulled,

the weather, and the degree of care exercised by the engineers and firemen in the management of the engines, and use of fuel.

The object of this Manual is to properly instruct engineers and firemen in the economical management of the engines, and use of fuel.

SOURCE OF POWER.

HEAT.

Source of Power.

Heat.

The prompt, safe, and speedy movement of trains is of the first importance upon a railway, and this is the work that locomotives must perform under the guidance of their engineers.

The next important requirement is the economical operating of the locomotives, accompanied by careful inspection and maintenance of the same, in order to guard against and prevent accidents necessitating expensive repairs. Modern locomotives are so constructed as to satisfactorily and economically do their work, and it remains for the engineers and firemen to cause them to do so, and this can easily be done by careful management. Locomotives derive all their power from HEAT, and in order that we may understand this *source of power*, which will assist us to properly and economically use it, we will consider a few illustrations of its cause, nature, and capacity for doing work.

Heat may be generated by a mechanical

process, such as the expenditure of force, and it may be generated by a chemical process, such as the combustion of fuel.

The rubbing together of two pieces of wood, the blows of a hammer, or the compression of air, each and all produce heat, and furnish illustrations of moving force converted into heat.

A cold lead bullet may be placed upon a cold anvil and struck with a cold hammer. The force of the descending hammer is arrested by the bullet. If we examine the lead, we find it is heated, the descending force of the hammer having been converted into heat; and we shall learn that if we could gather up all the heat generated by the blow and apply it without loss mechanically, it would furnish the power to lift the hammer to the height from which it fell.

When a train approaches a stopping-place, the brakes are applied; showers of sparks are produced by the friction of the brake-shoes against the wheels, and the train is brought to rest simply by converting the moving force which it possessed while running, into heat.

Knowledge such as this excited in the minds of scientific men a desire to investi-

gate this subject of heat, and find out its nature, cause, and general deportment under all conditions. The theory of heat generally accepted teaches that it is a *motion* of the smallest particles, or molecules, of the substance.

The correctness of this theory has been demonstrated beyond all doubt by many carefully conducted experiments. When a hammer strikes a bell, the motion is arrested but not destroyed. It is shivered into vibrations which affect our hearing as sound. Also when our hammer fell upon the lead bullet, its motion was transferred to the atoms of the lead, and announced itself to the proper nerve as heat.* Many careful experiments have been performed which leave no doubt that, under all circumstances, the quantity of heat generated by the same amount of force, is fixed and invariable. In this way it was proved that the amount of heat necessary to raise one pound of water one degree (1°) in temperature, is equal to that generated by a pound weight falling from a height of 772 feet against the earth. Also the same amount of heat

* Professor Tyndall.

would, if all applied mechanically, be competent to raise a pound weight 772 feet high; or it would raise 772 pounds one foot high.

In order to measure anything, we must first establish a standard or unit of measurement. So, in order to measure work, it has been agreed that the amount of power necessary to raise *one pound one foot high* shall constitute the unit of measurement of work, and is called a *foot-pound.*

As a foot-pound is the unit of measurement of work, so a quantity of heat sufficient to *raise one pound of water one degree of temperature* is the established unit of measurement of heat, and is called a *unit of heat.*

Let us take another glance at the results of converting moving force into heat. Knowing the weight of the earth and the velocity with which it moves through space, philosophers have calculated the amount of heat that would be generated, should the earth strike an object strong enough to stop its motion, and found that it would be sufficient not only to melt the entire earth, but to reduce it in great part to vapor.

The amount of heat thus developed would be equal to that derived from the combustion of fourteen globes of solid coal, each equal to the earth in size. "And if, after the stoppage of its motion, the earth should fall into the sun, as it assuredly would, the amount of heat generated by the blow would be equal to that developed by the combustion of 5,600 worlds of coal." *

Such knowledge has caused some scientific men, in speculating on the manner in which the sun's heat is maintained, to suppose that it is due to the showering down of meteoric matter upon its surface. Whether the supposition is correct or not, we do not know, but one thing we may be sure of, and that is, the heat and light of the sun is the source of nearly every motion which takes place upon the surface of the earth. By the action of its rays vegetation is enabled to draw support from the earth and the air, and in turn become the support of animals; which in turn become, together with vegetable products, the support of man, and furnish him with all the heat of body and power of muscle he may possess.

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* Professor Tyndall.

Many thousands of years ago the sunbeams, in the same manner as to-day, caused the growth of trees and plants which flourished in the atmosphere, then rich in carbonic acid, which passed into their formation, and was finally stored as coal in the depths of the earth. The sunbeams were invested in the building of these trees and plants, and a great amount of heat was expended, exactly equivalent to the amount of work done, in causing their growth. The heat was not lost, but *stored away*, as the heat from the burning of a pound of coal gives evidence.

The perfect combustion of a pound of ordinary soft coal yields 14,000 units of heat, each unit of which is capable, if mechanically applied without loss, to perform 772 foot-pounds of work. A pound of coal then contains within its unattractive exterior a store of *possible energy* capable of performing over 10,000,000 foot-pounds of work, or, expressed differently, capable of lifting ten tons over 500 feet high.

Because of many avenues of waste it is possible, by our present mechanical arrangements, to convert but a small part of this great power into actual and useful

work. But the above gives an idea of the vast store of possible energy in coal, which through certain conditions (its combustion) will generate heat, and which by suitable arrangements (a steam-engine and machinery) may be caused to perform almost any kind of work for us we wish.

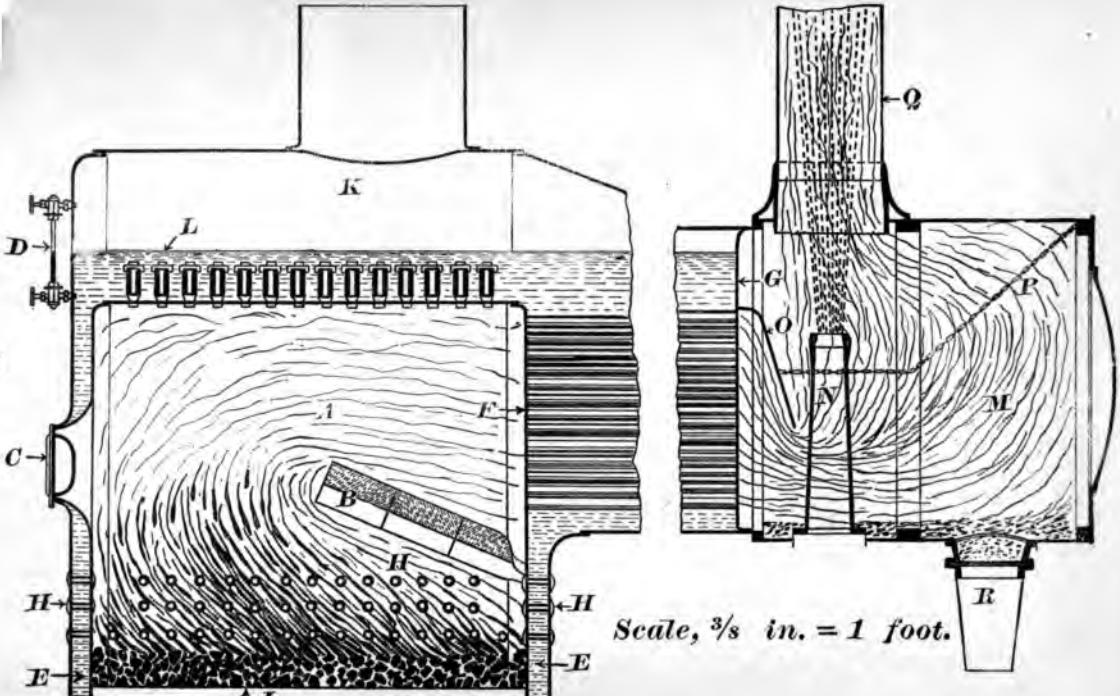
Let nature illustrate for us the power of heat to perform work. We know that if moisture be exposed to the heat of the sun it is "dried up," or, properly speaking, evaporated. By the process of evaporation the sun draws up great quantities of vapor from the surfaces of bodies of water exposed to its rays, the heat of which is expended in changing a portion of the water at the surface into vapor, and lifting it to mountain heights. The vapor condenses, and falls as snow upon the mountain-tops, and rain upon the valleys; the rain producing rivers, which in their flow to lower levels in obedience to gravity, can be made to perform various kinds of mechanical work, and turn wheels, grind corn, lift hammers, and saw wood.

The part that fell as snow upon the mountain-tops is like a lifted weight held at rest. It is possessed of possible energy,

properly called *potential energy*, because its energy or capacity for performing work is *stored up*, until the heat of the sun shall melt and release it to flow down the mountain. When, in the heat generated by the friction of the water along its bed in the mountain saw-mills, in the motion of the machinery turned by water-power, and the revolving mill-stones, we find that the heat which was expended in conferring potential energy upon the water by raising it aloft, re-appears, and is converted into work.

We daily see water, converted into steam and again invested with energy by heat, running the mill, the manufactory, communicating motion to the machinery in shops, and urging to reckless speed, if permitted, the locomotive with its train.

COMBUSTION OF COAL AND FIRING.



Scale, 3/8 in. = 1 foot.

A Fire-box, showing combustion and direction of gases.
B Brick arch.
C Fire-door.
D Water-glass.
E Water-legs.
F Back tube-sheet.
G Front tube-sheet.
H Hollow stays for admitting air.
J Coal fire on grates.
K Steam-space.
L Water-level.
M Smoke-box.
N Exhaust-pipe.
O Reflector-plate.
P Netting.
Q Smoke-stack.
R Cinder-hopper.

Combustion of Coal,

and Firing.

Combustion of coal is a chemical union of the atoms of the coal with the atoms of the oxygen of the air, to effect which union it is necessary that the atoms of the two named substances meet at a high temperature, called the temperature of ignition, which, for coal and coal gas, is that of bright red-hot iron, or about 1,800°.

At this temperature the attractions of the atoms of the coal and oxygen become so great that they *clash together*, and light and heat are the result of their collision.

Let us inform ourselves of the composition of coal and air. Coal is composed of several substances, as follows: carbon, hydrogen, nitrogen, oxygen, sulphur, and ash. The proportions in which these substances are found in soft coal are generally about as follows:

Fixed carbon	50	per cent.
Gaseous matter and moisture	40	"
Ash	10	"

Carbon, being the chief ingredient in the composition of coal, is entitled to our first consideration. It forms the solid portion of coal, or that part which, after the gaseous matter has been expelled by heat, remains upon the grate, and is burned in the solid state as coke. It is one of the most abundant of the elements of nature, and exists in several different states, or conditions; as, for instance, the diamond, black lead, and charcoal.

We can hardly think of three substances more unlike in their appearance than these, yet they are, and yield upon analysis, nothing but carbon.

In burning, if its combustion is complete, a pound of carbon yields 14,500 units of heat.

Hydrogen, the next important part of coal, is known only in the gaseous state, and is the lightest substance known. One atom of hydrogen gas will combine with one atom of oxygen gas, and the result of their union is vapor of water. The atom of oxygen is eight times the weight of the atom of hydrogen, while the atom of hydrogen is twice the volume of the former.

To avoid confusion upon such points, it will serve our purpose to disregard the

weights and volumes, and consider only the atoms of the different substances as they affect each other.

The combustion of one pound of hydrogen generates 62,032 units of heat, which is the greatest heat developed by the combustion of one pound of any known substance.

Nitrogen and oxygen will be considered in the study of air.

Sulphur is a mischievous element in coal. It exists in the solid state, mixed with iron and other impurities, and assists in the formation of clinker. The presence of moisture in coal simply has this effect: a part of the heat of the fire is consumed in evaporating the moisture, or water, but the amount is small in proportion to the heat given out by the fuel.

The ashes of coal are its impurities, and are due to incombustible matter contained in the vegetation of which the coal was formed, and to the presence of mineral substances in the ground. Clinkers are formed by the melting of these impurities when accumulated and subjected to a high temperature. They choke up the air spaces between the grates and obstruct the admission of air to the fire.

Air is composed of two gases, nitrogen and oxygen; two atoms of nitrogen and one atom of oxygen, each of the nitrogen atoms being double the volume of the oxygen atoms; thus making the volume of the nitrogen in the air four times that of the oxygen.

For the purposes of combustion, oxygen is the only part of the air that is used. It is the supporter of combustion, and the nitrogen is only a vessel, so to speak, in which the oxygen is delivered; the delivery once made, the vessel is no longer of any value, as far as promoting combustion is concerned. Indeed, Mr. C. Wye Williams, the earliest and most conspicuous writer upon the combustion of coal, declares it to be a "mischievous intruder," for it enters the furnace in volumes four times as great as the oxygen, and far from assisting in combustion, absorbs a great deal of heat in passing through the furnace.

The first thing that happens when coal is put upon a fire, is, the coal absorbs a great amount of heat, and the work heat performs when so absorbed, is to expel the gaseous matter of the coal, the constituents of which are two atoms of hydro-

gen and one atom of carbon vapor, called carbureted hydrogen.

Now, if the temperature is sufficiently high, as explained on the first page of this chapter, the attractions existing between the oxygen and gas are so intensified that they clash together, and light and heat result, and they are burned, the products of their combustion being vapor of water and carbonic acid gas.

In the union of the carbureted hydrogen and oxygen just described one might think the gases, having such powerful attractions for each other, would rush indiscriminately together, regardless of law or order. But this is not the case.

At the igniting temperature the hydrogen separates itself from its fellow constituent, the carbon vapor, and combines, atom for atom, with the oxygen present, forming *vapor of water.*

This is because the oxygen has a stronger attraction for the hydrogen than it has for the carbon, and not until the hydrogen meets and combines with its equivalent of oxygen does the carbon take its turn.

In its turn, the carbon vapor yields up *one* of its atoms to *two* atoms of oxygen, and in that proportion combines with

oxygen and is burned, forming *carbonic acid.*

In this manner the gaseous portion of the coal is expelled and consumed, leaving the most of the carbon yet upon the grates in a solid, incandescent state.

A proper supply of oxygen alone will enable it to perfectly burn, and yield up its greatest heat; that is, in burning to carbonic acid.

We know that each atom of carbon requires two atoms of oxygen to so consume it, and that a pound of carbon in so burning yields 14,500 units of heat. Should the admission of air to the fire be so restricted, because of ashes or clinkers on the grates, that two atoms of oxygen would not be present to unite with each atom of carbon, the carbon would then unite, atom for atom, with the oxygen present, and would be imperfectly burned, and form carbonic *oxide*, instead of carbonic *acid*, and in so doing would yield but 4,452 units of heat, or 10,048 units less than if the same amount of carbon had been supplied with its proper equivalent of oxygen —two atoms—and perfectly consumed.

Hence, it is apparent that if the supply *of air to* a furnace is restricted by any

means, the heat of the fire is greatly reduced.

Without dwelling longer upon details, it may be stated that the oxygen of the air is just as much the fuel consumed in a furnace, as the coal upon the grates, and the gases expelled from it; and that on the quantities in which these elements combine depends the heat of the fire. Lack of sufficient quantity of either is attended with great waste. These quantities have been determined theoretically, showing that 150 cubic feet of air, containing thirty cubic feet of oxygen gas, is needed for the perfect combustion of one pound of coal.

This is known as the minimum theoretical quantity. All writers upon the subject agree that *practically* about twice this amount is necessary to secure the best results.

Mr. Thomas Box, in his "*Practical Treatise on Heat*," says in regard to this matter: "The quantities of air as found by the preceding calculations are, as stated, the *minima* absolutely necessary to furnish the oxygen required to support combustion.

"Practice has led to the use of much larger quantities, the principal reason

being, perhaps, to avoid the formation of carbonic *oxide*, instead of carbonic *acid*, which would be the case if the supply of oxygen were too small, the result being a great loss of useful effect.

"Analyses of the air that has passed through the fires of well-arranged steam-boilers, show that the air still retains half the normal amount of oxygen, and that double the minimum quantity [of air] has been used, and we may admit, as a practical rule, that the quantity of air should be double the minimum theoretical quantity."

So we have in round numbers, about 300 cubic feet of air that must pass through our fire to secure the best results from the burning of each pound of coal placed upon it.

Shovels, such as locomotives are generally provided with, hold, when ordinarily full, fourteen pounds of coal. When an engine is in need of a fire, generally four or five shovelfuls will be scattered, or should be, over the surface of the fire.

We will say four shovelfuls, fifty-six pounds, and that quantity will last three minutes; 16,000 cubic feet of air, about eight box-carfuls, must pass through the

fire in this short time to effectually burn the charge of coal.

An immense amount of air; yet it is the business of the exhaust in going up the stack to pump this quantity of air through the fire, and it will perform its part if the grates are kept clear of ashes and clinkers; and we know that if it is not supplied, or if, because of obstructions to its passage, the amount falls far short of this, each atom of the carbon of the fifty-six pounds of coal will unite atom for atom with the oxygen admitted, and form carbonic oxide, and we will lose over 10,000 units of heat for each of our pounds of carbon. This is 75 per cent. (fixed carbon and vapor) of the coal, or forty-two pounds. If we lose 10,000 units of heat on each of these, we shall lose altogether 420,000 units. We know that one unit of heat is equivalent to 772 foot-pounds of work; we measure our loss, and find it was capable, if it had been saved and mechanically applied without loss, of lifting 100 tons 1,600 feet high.

It appears too bad that so much air is needed, and that such a small portion of it (1-5) is useful in assisting combustion. It seems that nitrogen takes up all the room, and is useless, only an absorber of

heat, and we are ready to say, a "mischievous intruder."

Let us hear what Professor Faraday said about it. "This other part of the air is by far the larger portion, and it is a very curious body when we come to examine it; it is remarkably curious, and yet you say, perhaps, that it is very uninteresting.

"It is uninteresting in some respects because of this, that it shows no brilliant effects of combustion. If I test it with a taper as I do oxygen and hydrogen, it does not burn like hydrogen, nor does it make the taper burn like oxygen. Try it in any way I will, it does neither the one thing nor the other; it will not take fire; it will not let the taper burn; it puts out the combustion of everything There is nothing that will burn in it in common circumstances. It has no smell; it is not sour; it does not dissolve in water; it is neither an acid nor an alkali; it is as indifferent to all our organs as it is possible for a thing to be.

"And you might say, 'It is nothing; it is not worth chemical attention; what does it do in the air?'

"Ah! then comes our beautiful and fine results shown by an observant philosophy.

"Suppose, in place of having nitrogen, or nitrogen and oxygen, we had pure oxygen as our atmosphere, and what would become of us?

"You know very well that a piece of iron lit in a jar of oxygen, goes on burning to the end. When you see a fire on an iron grate, imagine where the grate would go if the whole of the atmosphere were oxygen.

"The grate would burn up more powerfully than the coals, for the grate itself is even more combustible than the coals which we burn in it.

"A fire put into the middle of a locomotive would be a fire in a magazine of fuel, if the atmosphere were oxygen. The nitrogen lowers it down, and makes it moderate, and useful for us; and then, with all that, it takes away with it the fumes you have seen produced; * * * dispenses them throughout the whole of the atmosphere, and carries them away to places where they are wanted to perform a great and glorious purpose of good to man, for the sustenance of vegetation, and thus does a most wonderful work, although you say, on examining it, 'Why, it is a perfectly indifferent thing.'"

What the professor so gracefully said is true, and we must regard the nitrogen as a safe envelope for the very active and destructive oxygen.

What was said of iron being a combustible substance is true, and all that is required to make it burn is the presence of pure oxygen and a high temperature.

The combustion of a diamond, as described by Professor Tyndall, will serve as a good general illustration of the act of combustion, and its generation of heat.

"Everybody now knows that this brilliant gem is composed of the same substance as common charcoal, graphite, or plumbago. A diamond is pure carbon, and carbon burns in oxygen.

"Here is a diamond held fast in a loop of platinum wire; heating the gem to redness in this flame, I plunge it into this jar, which contains oxygen gas.

"See how it brightens on entering the jar of oxygen, and now it glows, like a little star, with a pure white light. How are we to figure the action here going on? Exactly as you would present to your minds the idea of meteorites showering down upon the sun.

"The conceptions are, in quality, the

same, and to the intellect the one is not more difficult than the other.

"You are to figure the atoms of oxygen showering against this diamond on all sides. They are urged toward it by what is called chemical affinity; but this force, made clear, presents itself to the mind as pure attraction, of the same mechanical quality, if I may use the term, as gravity.

"Every oxygen atom as it strikes the surface and has its motion of translation destroyed by its collision with the carbon, assumes the motion we call heat; and the heat is so intense, the attractions exerted at these molecular distances are so mighty, that the crystal is kept white-hot, and the compound, formed by the union of its atoms with those of the oxygen, flies away as carbonic acid gas."

The importance of providing for a free admission of air through the grates, in quantities sufficient to effect as nearly perfect combustion as possible, should never be lost sight of.

We have noted the evil results of too little air in a single instance, from the imperfect burning of one fire, or four shovelfuls of coal; that *only one-third* of the useful heat of the coal was yielded up,

simply for the want of *more air*, and *two-thirds were wasted.* Think how great the waste must be on an engine where the conditions, and consequent waste described, during the burning of that one fire, are the existing conditions for hours together; sometimes for the greater part of the trip; sometimes for the last one or two hours of the trip. In either case the waste is very great, and is, in such cases, shameful, because almost always unnecessary

Locomotives are provided with suitable arrangements for frequently shaking the grates; which will effectually prevent the accumulating of ashes upon them, and the formation of clinkers, which result from the accumulated ashes melting together. Frequent shaking of the grates, therefore, is necessary to a full supply of air, and to prevent the forming of clinkers, which are the arch-enemy of perfect combustion and economy.

Some firemen habitually neglect shaking the grates, and do so to save themselves the work of cleaning out the ash-pan. That such neglect is a wasteful practice they know, for they have to shovel more coal into the fire-box to keep up steam,

when their grates become choked with ashes and clinkers, than when air has free access through them. But the dread of having to hoe out the ash-pan, causes them to prefer to shovel a double quantity of coal, rather than engage in a task so disagreeable. Whoever desires to advance, and excel in his calling, should never allow the dread of an unpleasant task to cause him to shirk his work in any way, or stop short of *doing the very best thing*, whatever that may be, to make his work as excellent as possible, feeling sure that success is only the result of careful work.

We have dwelt at some length on the necessity for a free admission of air through the grates, but it must not be taken that the more air the better, for all in excess of the quantity to supply the needed equivalent of oxygen for the carbon and gaseous portion of the coal, has no effect except to absorb the heat of the fire and carry it off.

Care, therefore, must be taken to keep the bed of fire thick enough, and of uniform depth over the entire grate surface to prevent access of too much air.

The time to guard against this most carefully is in shaking the grates, which,

while running, should only be done after a fresh fire has been put in.

Even then care must be taken not to shake them so hard as to injure or make holes in the fire. SEE NOTE 1. IN BACK

During the first twenty or thirty miles of a trip, while fire is light and thin, it is advisable to run with front damper closed, if engine steams freely, to prevent access of too much air.

From the combustion of the diamond a useful lesson should have impressed itself upon firemen of the necessity of breaking the coal into small pieces.

A dusky diamond in a fire-box, after its gaseous matter is expelled, is burned under exactly the same conditions as the brilliant gem in the jar of oxygen. The surface exposed to the striking atoms limits the battle ground, and the intensity of heat depends upon the rapidity of combustion, which in turn depends, in part, upon the surface of the coal exposed to the attacking atoms. By breaking a large lump of coal into small pieces, its exposed surface is greatly increased, which will materially assist its rapid burning and generation of intense heat. For the same reason the coal should be *scattered* over the surface of the fire as

it is thrown in, instead of being dumped in heaps. Then, each piece will be brought into immediate and separate contact with the hot surface of the fire, in which way it will burn most rapidly, and yield the greatest amount of heat, and form the least smoke.

Heavy firing should never be indulged in. It is a bad and wasteful practice in many ways, because the coal, when put upon the fire in large quantities, gives up great volumes of gas, for the combustion of which there is not present sufficient air, and the gas escapes unconsumed as smoke, having acted only as an absorber of heat. The air jets through the sides of the fire-box, and the aperture in center of fire-box door are intended to supply air above the fire for the combustion of the gaseous portion of the coal; but when the charges of coal are heavy, the gas is produced in such large quantities that it is impossible for it to be supplied with its proper equivalent of air.

Heavy firing is also a bad practice because a large quantity of coal thrown upon a fire is, at first, a greedy absorbent of heat, and cools the temperature of the fire-box and flues, causing contraction, followed by an

intensely hot fire, causing expansion of same, which results, in time, in leaking flues, broken stay-bolts, and general injury to the boiler.

Care should be taken to keep the steam pressure as nearly constant and steady as possible, to avoid these evil results.

Some firemen have a habit when putting in a fire of exerting themselves to see how rapidly they can swing the fire-box door, and follow each shovelful with another, until the fire is all in.

This is wrong, for the same reasons that heavy firing is wrong. A much easier and more economical way is to commence in time, and put the fire in leisurely, allowing the door to remain closed a few moments between each shovelful, for the furnace to regain its temperature.

A fire should never be put in while the engine is starting a train. It should be the fireman's aim to *have his fire in before the engine starts*, and keep the door closed while the engine is working hard forcing the train into speed. Some firemen pursue the opposite course, and no matter what the condition of their fire is, wait until the engine begins to start the train

before they make a move toward putting in a fire.

The first exhaust is the signal they wait for; when it goes resounding up the stack the fire-box door is pulled open, and blast after blast of cold air, following the escaping exhaust, sweep through the open doorway, through the low temperature of the fire-box, and spend their force and cooling effect upon the flue-sheet and flues. Coupled with a charge of cold, *heat-absorbing* fuel, it is small wonder the gauge shows a fallen steam pressure of ten or twenty pounds by the time the fire is all in. The proper way would have been in such a case for the fireman to have slipped in his fire *just before* starting, and if engine had been standing some time, and fire was at a low heat, a slight application of the blower for a few moments before the engine started would heat up the coal and start the fire burning. Then when the engine was started, the fire would be *in*, and in good condition, and the door could be left closed until the train was well in motion and reverse-lever pulled back to short cut-off; when, if necessary, a fire could be put in under the favorable conditions of a soft draft.

The results of this way would be less work for the fireman, economy of coal, and no loss of steam pressure and consequent chilling of boiler, and no cold air rushing through fire-box. All good results, and amounting each month to considerable labor and fuel saved and abuse of boiler avoided.

For like reasons, to prepare in *advance* for emergencies, or changed conditions, firemen should always prepare the fire *before* injector is started, when the engine has run any distance with it not working; bearing in mind that in firing it is easier and more economical to keep up, than to catch up.

A careful and thoughtful fireman will, before putting in each fire, *think ahead*, or anticipate the work the engine is going to do while that fire is burning, and he will regulate the amount of coal he puts upon the fire accordingly.

Take the engine just about starting a train; the fireman knows the condition of the fire, and thinks ahead of the way the engine will be worked while forcing the train into speed, and of how hot his fire must be to maintain the steam pressure unreduced He remembers that while the

engine is to be worked hard, the injector will be left off, and no cold water will be put in the boiler until the engine is working easier.

This he remembers will enable him to keep up the steam with a less hot fire, and therefore less coal than if the injector was started with the engine; so, if he puts in the unnecessarily heavy fire, the surplus heat generated will blow off at the safety valves, and declare his lack of judgment. So he anticipates the work the engine is to do, and regulates his fire accordingly, and the engine starts with just enough coal on the fire to "hold" it, and prevent the exhaust from "pulling" it, and to maintain the desired pressure of steam without blowing off.

This becomes his formed habit, and he finds himself always measuring the coal to his fire to conform to its needs, with an eye that looks beyond its present conditions of heat and draft, to what will be those conditions before the fire he is putting in will have yielded up its heat; and he regulates the amount of coal to secure the best and most economical results, and prevent loss.

Mr. Angus Sinclair, in his book on

"*Locomotive Engine Running and Management*," says: "The highest type of fireman is one, who, with the smallest quantity of fuel, can keep up a good head of steam without wasting any at the safety-valves.

"He endeavors to strike this mean of success by keeping an even fire; but it sometimes happens that the closest care will not prevent the steam from showing indications of blowing off. When this is the case, he keeps it back by closing the dampers, or, if that is not sufficient, opens the door a few inches. Immense harm is done to flues and fire-boxes by injudicious firing."

Understanding how necessary air is to combustion, we know why the burning of our fire is checked by dropping the dampers. The supply of air, the other part of the fuel, is cut off, and combustion suspended.

So when too much coal has been put upon the fire, which in burning is generating too much heat, rather than open the fire-door, and admit cold air to counteract the heat which the coal still being allowed to burn is giving out, it is more economical and less injurious to the boiler to close the

dampers, whether engine is working steam or not, and thus suspend combustion until greater heat is needed.

When it becomes necessary to open the fire-door to prevent the steam from blowing off, or to cause it to cease doing so, the door should never, while the engine is using steam, be pulled wide open and left so until the boiler cools. The inrush of cold air causes rapid cooling and contraction of the fire-box, and is especially hard upon the flues and flue-sheet. The door held just ajar, or swung to and fro, secures the best results generally. It is not an evidence of good firing, however, to even do this very often, especially with a fireman familiar with an engine, but it is a declaration of carelessness, or bad judgment. Either, when putting in the fire that generated the surplus of steam, he was careless, and gave no heed to his work; or, in measuring the quantity of coal he thought his fire needed, he put in too much.

The result in either case is a waste of fuel, and the noisy censure of the "pop" should cause him to try to be more careful, or correct. Mr. Michael Reynolds, in his book on English "*Locomotive Engine*

Driving," says: "There is an idea abroad that, unless the steam blows off mad there can be no very great demonstration of skilled enginemanship. There can not be a much greater mistake.

"When steam, water, and fuel are being thrown away through the safety valves, it is a positive proof of the existence of either one or both of the following evils: either the engine is too small for its work, or the engine is too great for its man, and the engine or the man would do better on short train work; the former until it was convenient to place it under a steam-hammer, and the latter until he had learned how to *bottle his noise*, or anyhow until, for the sake of the engine, he could enable her to obtain a fair position on the coal list."

Frequently with a light, clean fire, when engine is standing, and the blower slightly on, a drumming noise is made. It also occurs sometimes when the engine is running and fire-door is opened.

It is caused by the hydrogen expelled from the coal combining in certain proportions with the oxygen present, forming oxyhydrogen gas, an explosive compound, when subjected to a high temperature.

The explosions occur in rapid succession, and cause the drumming noise, which is unpleasant for most people to hear.

For this reason it should be prevented on passenger engines, and on freight engines at stations, or while passing or standing near passenger trains; by closing one or both dampers, or opening fire-door sufficiently, whichever is most effectual.

For the same and economical reasons, engines should not be permitted to emit smoke while about stations and depots, and should be prevented from doing so by closing dampers, or opening fire-door and using blower slightly, or if engine is working, by light and careful firing—whichever plan best suits the circumstances.

Special care should be exercised in preparing fire to start from large depots, where smoke is most objectionable, to do so without emitting smoke.

If the fire is at a low heat this can best be accomplished by easy stages; by scattering one or two shovelfuls of finely-broken coal over the surface of the fire, and, with fire-door ajar and blower on a little if necessary, giving it time to burn well before another charge is put on.

Also before entering the limits of such depots, the fire should be prepared so as to prevent emission of smoke, or falling temperature of boiler while in depot limits.

This may be done by putting last charge of coal on fire in time, so it may be burned down sufficiently on reaching the depot to prevent smoke.

Good judgment, intelligence, and care, are the necessary qualifications of a good fireman, *and are the attributes of success*, accompanied by sobriety, and cleanliness, and diligence to learn and understand the construction, care, and proper management of locomotives, and the rules and regulations of his company.

INSTRUCTIONS FOR FIREMEN.

1. Upon arriving at their engines firemen must assure themselves of the condition of the fire, the ash-pan, and see that the grates are all connected and in order, and that there are upon the tender the necessary tools for handling the fuel and attending to the fire. Anything in bad order must be reported to the engineer.

2. Firemen must have their fire in readiness before the engine starts the train, and have sufficient fuel on the fire to hold it, and keep up steam while engine is starting train, avoiding, as much as possible, opening the fire-door while exhaust is strong.

3. Coal must be broken into pieces as near egg size as possible, and when put upon the fire must be scattered over the fire's surface as evenly as possible, giving the sides and corners the preference, but must never be thrown in heaps on any part of the fire.

4. Firemen must fire lightly and frequently, and avoid heavy firing. They must use upon engines with 15-inch cylinders and less, but two shovelfuls to each

fire; with 16-inch cylinders, but three shovelfuls to each fire; with 17 and 18 inch cylinders, but four shovelfuls to each fire; with 19 and 20 inch cylinders, but five shovelfuls to each fire. The fire-door must be closed between each shovelful when engine is working.

5. Firemen on passenger engines, after the first thirty miles have been run, must shake their grates lightly every thirty miles. Firemen on freight engines, after the first twenty miles have been run, must shake their grates lightly every twenty miles.

6. When clinkers become formed in the fire-box firemen must improve the first opportunity to clean them out, and must not try to run the last part of a trip with a clinkered fire, if there is opportunity to clean it.

7. Firemen must keep steam pressure within the limits of ten pounds, and must not permit it to change rapidly either way. While injector is working after steam is shut off from cylinders, the blower must be used when necessary to prevent change of temperature of boiler.

8. To prevent or stop blowing off, increase boiler feed, or, if necessary, drop dampers.

If necessary to open fire-door for this purpose while engine is working, open but slightly, or swing open and shut.

9. Smoking and drumming of engine must be prevented at stations, or while near or attached to passenger trains.

10. Ash-pans and fires must not be cleaned near any bridge or culvert, depot or building, or on any frog or switch; and in all cases fire must be thoroughly drowned with water before being left.

Instructions for Firemen and Hostlers.

11. Hostlers must be sure that flue-sheets are cleaned of adhering clinker before engines are fired up, and that the fire is evenly placed over the entire grate surface.

Hostlers and firemen must be particularly careful that a bed of fire is over the forward portion of the grates, *and next the flue-sheet*, before blower is used.

12. At all times blower must be used as lightly as possible, to effect the desired purpose.

13. After fire has been removed from fire-box, the dampers and fire-door must be kept closed while engine is being handled.

FORMATION OF STEAM AND BOILER-FEEDING.

Formation of Steam, and Boiler Feeding.

Water is composed of one atom of hydrogen gas and one atom of oxygen gas, the oxygen being eight times the weight of the hydrogen; making water by weight, eight parts oxygen and one part hydrogen.

It is superior to all known substances, as an agent of heat to effect the performance of work. Aside from its abundance, two qualities go to form this superiority, its capacity for absorbing heat, and its capacity for holding heat, or storing it up.

It is the most powerful absorber of heat of all liquids, which quality makes it one of the most useful agents of good to man of all the elements of nature. By currents in the ocean flowing from tropical to colder climates it regulates and modifies the heat of summer and the cold of winter throughout vast regions of sea and land. It absorbs the heat of the sun-beams and rises as vapor to fall again as refreshing showers of rain. It absorbs the heat of

the furnace and makes it available for useful purposes. It absorbs the heat of the conflagration and in reducing the burning material below the temperature of ignition "puts out" the fire and saves cities and homes from ruin.

The capacity of water for *storing up heat* is greater than that of all other substances, and is a *particularly valuable quality* in locomotive operating.

This quality varies as widely in different substances as their weights, and is called "specific heat," and is measured by the amount of heat necessary to raise one pound of the particular substance 1° of temperature.

A pound of water requires one unit of heat to raise its temperature 1°.* The same amount of heat will raise one pound of other liquids 2°; or one pound of iron, zinc, copper or brass 9°, or nine pounds of either metal 1°; or twenty pounds of silver or tin 1°; or thirty pounds of mercury, gold, or lead 1°.

In fact, water is the great natural storehouse for heat, and the amount of heat

*The specific heat of water varies slightly with the temperature, but the difference is small, and for most practical purposes may be neglected.

and energy that may be stored in a few pounds of water is almost incredible.

Water freezes at 32° above 0° of the Fahrenheit thermometer, and boils and is converted into steam at 212°.

Let us take a pound of water, at the lowest temperature it is capable of existing in the liquid state, 32°, and applying heat to it, convert it into steam, and note the events of the process. Let us place the water at the bottom of a tube of indefinite length, open at the top, and of an area of one square foot, or 144 square inches.

At this temperature, one pound of water measures 27.7 cubic inches, and will cover the bottom of the tube to a depth of about two-tenths (.2) of an inch.

If we apply the flame of a lamp to the tube beneath the water, the temperature of the water will begin to rise, and continue to do so until it reaches 212°, the boiling point at atmospheric pressure, or 14.7 pounds to each square inch, which is the weight or pressure of the air on the surface of the earth.

The water will then be slowly evaporated into steam; but the temperature of both the water and the steam will continue

steadily at 212°, until all the water has been evaporated; 181 units of heat were imparted to the water in raising its temperature to the boiling point at this pressure, and 965 heat-units more must be supplied to convert the pound of water into steam, a total of 1,146 units of heat.

The 965 units necessary to change the pound of hot water into steam is called the *latent heat of steam*, and the heat thus absorbed and insensible to the thermometer devotes its energy to overcoming the force of cohesion, which is the force that holds the particles of substances together.*

It is in breaking the last fetters of cohesion and settling the minute particles of water free to fly away in the vaporous form that the 965 units of heat are used.

Our tube having an area of 144 square inches, the steam forms a column twenty-seven feet high, making twenty-seven cubic feet of steam. As steam of high pressure is necessary for locomotive operating, we will take a case of generating steam of 145 pounds effective pressure; which is the pressure indicated by

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* Also to melt ice of 32° to water of same temperature, requires 142.4 heat-units; and this is called the *latent heat of water*.

the steam-gauge; the atmospheric pressure is not indicated because the pressure of the air on the outside of the boiler exactly neutralizes the pressure within. Taking the same quantity of water at same temperature, and in same tube, we place a piston weighing 145 pounds per square inch on the top of the water, supposing the piston to be perfectly steam-tight and capable of moving without friction.

The weight of the air on top of the piston will further increase its weight to 159.7 pounds per square inch. We begin to apply heat—181 units raises the temperature to 212°—but no boiling takes place as on the previous occasion. The reason for this is that by increasing the pressure on the surface of the water, we have introduced a powerful antagonist to its boiling, which we must analyze.

When heat is transmitted to water, the particles nearest the heating surface absorb it and become heated and expand in volume, or size, and thus are made lighter in weight than the colder particles of water above them.

Then, just as a drop of oil rises in water, because of its lighter weight, our

drop of heated water rises through the water above it to the top surface.

Metals will transmit heat through their bodies, from one particle to another; not so with water. It must become heated by *circulation;* each particle of water as it becomes heated rises through the water above, retaining its heat in a great measure until it arrives at the top surface, there to give it up, contract, become heavy, and sink again, to be re-heated, until the temperature of boiling, or ebullition, is reached, when our drop of heated water, as it touches the hot metal sheet of the furnace, is changed into a bubble of steam.

But, in order to exist for a moment as such, it must be able to resist two things: the weight of the water above it, and the weight of the pressure above the water. We know what a frail thing a bubble is; we know that water is a heavy substance, and that even the pressure of the air is 14.7 pounds on each square inch of surface; we increase this pressure 145 pounds more to each square inch. How can a thing so frail as a bubble be formed under such a pressure?

To be formed under such conditions, the

elastic force of the steam inside the bubble must exactly equal, and neutralize the force of the pressure without; if the outside force was greatest, the bubble could not be formed.

This is the true definition of the boiling point; it is that temperature at which the tension of the steam formed exactly balances the pressure above it.

Heat is the source from which the bubble of steam must draw its force to cope with this pressure; so it is plain that the greater the pressure, the greater the amount of heat necessary to enable the steam to form. So we find that the temperature at which our water boiled with simply the pressure of the air upon it, is incapable of causing the formation of steam under the increased pressure we now have.

We continue to apply heat; forty more units increases its temperature to 251°, still no boiling; forty-nine more heat-units raises its temperature to 300°, but no signs of ebullition yet appear; and not until we have added almost sixty-seven more units of heat, and increased the temperature of the water to 365°, does the water boil and generate steam of sufficient tension to equalize the pressure on its surface.

The latent heat of steam of this pressure is 856 units instead of 965 units, as in steam of atmospheric pressure.

In converting our pound of water of 32° temperature, to steam of 365° temperature and 145 pounds pressure, we have imparted to it 337 heat-units to raise its temperature to the point of ebullition, and 856 units, its latent heat, to change it into steam—a total of 1,193 units of heat. The steam in forming raised the piston two and three-quarters (2¾) feet, and occupies a space of two and three-quarters (2¾) cubic feet.

Let us glance at this web of relations: Heat, the source of power; water, the great absorber and store-house of heat, the agent to communicate that power through the means of the steam-engine; the locomotive requiring for its operation high pressure steam, which requires in turn 1,193 units of heat per pound of water changed to steam, 337 units of which is stored in the water in heating it to the temperature of ebullition, leaving a further application of 856 units necessary when it is desired to convert the water into steam.

This fact, small as it appears, is of great

importance in locomotive operating, and affords an opportunity to economize in the use of fuel, only equaled by the economy resulting from the expansive use of steam.

The nature of a locomotive's work in starting trains and forcing them into speed, climbing hills, and then running down hills and into stations with steam shut off, necessitates great irregularity of the application of power.

Now working at full stroke, starting a train; now cutting off at fifteen inches, struggling into speed; now, as speed increases, "cut back," to six or five inch cut-off; now steam entirely shut off while train runs into a station. So the round goes. A struggle, succeeded by a calm; soon to be followed by another struggle, in which all the energy of the engine is exercised. The exhaust resounding up the stack, creating a fierce draft through the fire; the late cut-off of the valves allowing great quantities of steam to enter the cylinders, and each exhaust to subtract a thousand units of heat from the boiler, necessitating an intensely hot fire and immense consumption of coal.

"In time of peace prepare for war," is a maxim full of wisdom, and applicable to

locomotive operating. From the nature of its work, a locomotive is necessarily being continually subjected to sudden drains upon its resources, and as its source of power is heat, it is well for the engineer to avail himself of every opportunity that offers to gather in a reserve store of heat, as great as possible, that it may assist his engine to easily and economically meet the requirements of hard work. Such a store of heat is to a locomotive as a reserve fund, or capital stock is to a bank; it may be drawn upon with great advantage in emergencies.

Such an emergency exists whenever an engine is starting a train or forcing it into speed, or taking a run for or climbing a hill. And every moment of time steam is shut off descending hills, approaching and stopping at stations, water-tanks, and crossings, affords an opportunity to utilize the heat-absorbing and storing qualities of water to lay up a store of heat which will enable it to easily meet coming emergencies.

Let us take a case of a locomotive starting out, without any preparation having been made for the struggle ahead of starting the train and forcing it into speed.

The engine starts the train, and the water in the glass indicates the water in the boiler at a safe enough level, but the glass is less than half full.

The engineer does not wish it to get any lower, so starts the injector, and regulates it to supply a quantity of water to the boiler equivalent to the amount being converted into steam and used.

The feed water is 32°, and for each pound of water evaporated to steam of 145 pounds pressure the fire must furnish 1,193 units of heat; to do which it must be forced to its utmost capacity regardless of consumption of coal.

The steam shows indications of falling pressure, to prevent which heavy and frequent firing is resorted to, and the fire-box door is kept on the swing, permitting, at each opening, great volumes of cold air to be drawn by the exhaust through fire-box and flues. Of course, this lasts but a few minutes, while the engine is struggling into speed, but in those few minutes a great and unnecessary consumption of fuel took place.

To illustrate this, we will take a case of another engine starting a train under different management.

Our engineer, on this occasion, is a thoughtful man, and looks ahead of the present moment, and anticipates the work his engine must perform.

Knowing a sharp, hard task is at hand for his engine, he has *prepared* her to easily and economically perform it.

Knowing that heat is the source of his engine's power, and knowing the capacity of water to store up great quantities of that power, he has availed himself of the opportunity he has had, before coupling on to his train, to store away in his boiler *eight hundred thousand units of heat* that shall be as a stock capital to draw from in the emergency before him.

His water-glass indicates that his boiler is as full of water as it properly may be; it is up within two inches of the top of the glass.

The steam-gauge points at 145, and, as a good fireman accompanies this engine, a fire is put in just before the engine starts, just sufficient to hold the fire and supply an amount of heat, easily (as our fireman knows) within one-half the capacity of the furnace.

The train is started. The boiler being full of water, the injector is left off; and

although the engineer works his engine as hard as the other engine was worked, it seems like a different sort of engine. The fireman is on his seat-box, and leaves the shovel and the fire-box door alone, the very two things most industriously used on the other engine; yet the steam-gauge indicates a steady pressure, and the force of the exhaust and increasing speed of the train declares that the engine is doing its work.

As speed increases, the reverse-lever is pulled back, shortening the cut-off of steam, and reducing the draft. Not a shovelful of coal was put in while the engine was struggling into speed, but now the fireman puts in a fire, after which the engineer starts the injector; the glass is yet half full of water, showing that his reserve store of heat is not yet exhausted, and he could draw upon it further if he wished.

The water-space of the boiler of an ordinary four-wheel coupled engine (18 x 24), which the eleven visible inches of the water-glass represents, and indicates the rise and fall of water in, will hold forty-four cubic feet of water. At the temperature and pressure of 145 pounds per square inch, one cubic foot of water weighs 55.9 pounds.

A rise or fall of one inch of the water in the glass represents an increase or decrease of four cubic feet, or (4 x 55.9 =) 223.6 pounds of water.

One cubic foot of water at 145 pounds pressure is stored with 18,850 units of heat, therefore each inch of water in the glass represents a store of heat in the boiler of 75,400 heat-units.

The stored heat represented by a full glass of water then in this boiler is (11 x-75,400 =) 829,400 units.

We now perceive what caused the wide difference in the performance of the two engines just considered; and why the engineer in the second case was able to get so much work out of his engine with such a small outlay of fuel, compared with the performance of the first engine.

In the first case, each pound of steam as used had to be supplied with its *total heat*, 1,193 units.

In the second case, each pound of steam as used had only to be supplied with its *latent heat*, 856 units.

The engineer in the first case had no reserve store of heat to assist him, so he had to draw upon his furnace for the full supply, which was beyond its capacity,

and forced firing, with all its attendant evils and losses, followed.

The heavy charges of coal put upon his fire gave up great volumes of gases, which, in the second of time they remained in the fire-box, were unable to meet their equivalent of oxygen, and so passed into the flues, where the temperature was below ignition, and were expelled from the stack as smoke without having *yielded up even the heat they absorbed in escaping from the coal;* so that a great portion of the heat generated by the combustion of the carbon burning in the solid state on the grates was absorbed by these gases and carried off.

The second engineer having an abundant store of heat in his boiler, had to draw but lightly upon his furnace, and for every inch the water fell in the glass he drew upon his store for 75,400 heat-units, and relieved his furnace of the task of furnishing that amount of heat during the emergency. The heat required of the fire-box was so easily within its capacity that but a light charge of coal was put on the fire; the small volume of gases given up by which met in the fire-box their equivalent of oxygen and were quite, or nearly, perfectly consumed, as proved by the absence

of smoke, and in their combustion gave off intense heat.

In practice, the saving of fuel effected by starting out with boiler properly full of water, heated up to the proper temperature, and leaving injector off until the train has been forced into speed, is very great. Starting trains is the hardest work that locomotives must perform, and unless they are assisted during this emergency by the above method, the consumption of fuel is extravagant.

Take a case of an engine starting a heavy freight train, where injector is started with the engine.

If the fire is in good condition, a charge of at least five shovelfuls of coal must be put upon it to start with, soon to be followed by another charge of at least four shovelfuls, and generally another charge of same quantity before the engine is put working at short cut-off. Total, thirteen shovelfuls of fourteen pounds each = 182 pounds.

Take the same engine with same train, and fire in same condition at start, but boiler sufficiently full of water to allow of the injector being left off during the hard work; a fire of four shovelfuls of coal, or

(4 x 14 =) fifty-six pounds, to start with, will be all that is needed to force the train into speed in the same distance and time as on the previous occasion, when three fires were needed, saving 126 pounds of coal, 100 pounds of which may be counted as clear gain, the other twenty-six pounds having been previously used to generate the heat stored in the water (represented by four inches in the glass), which heat has just been utilized in assisting the engine to economically start the train.

Nearly the entire amount of heat generated by the combustion of coal can be absorbed by water in a locomotive boiler when the engine is standing, or steam is shut off, and simply the natural draft acts upon the fire, slightly stimulated, if necessary, by the blower.

Take, for instance, the forty-four cubic feet of water-space in our boiler that we can safely use to store and draw upon for heat; we can store in it 829,400 units of heat, which amount would be generated by the perfect combustion of fifty-nine pounds of coal.

In practice, a fire of five shovelfuls, or (5 x 14 =) seventy pounds, will generate

the amount of heat necessary to fill this space with water, and maintain the temperature and pressure of 145 pounds.

This would be at the rate of 6½ pounds of coal per four cubic feet of water, or one inch in glass.

Twenty-six pounds would put sixteen cubic feet of water in the boiler (four inches in glass), and store in it 301,600 units of heat; and we have just illustrated how that store, drawn upon to assist in starting the train, saved 100 pounds of coal.

By carefully following this method the cost of starting trains can be greatly reduced, and every engineer should zealously improve every opportunity that offers, to fill his boiler with water as full as it may properly be before starting his train; and avoid putting water in the boiler while the engine is working hard, but draw liberally upon his store, for it can be easily and cheaply restored when steam is shut off. Care must be taken while injector is filling up the boiler to prevent any great variation of temperature, or reduction of steam pressure, to prevent which the blower should be slightly used if necessary.

A careless habit that some engineers indulge in of allowing the injector to supply the boiler with more water than what is being used as steam while the engine is engaged in ordinary work, such as running along on level road, is responsible for much waste of coal. When this is the case, the fire must be forced to furnish more heat to keep up the steam pressure than what would be necessary if the injector supplied only an amount of water to the boiler equivalent to what is being used as steam.

The proper way to feed the boiler while the engine is engaged in such work is to adjust the injector so as to supply an amount of water to the boiler slightly *less* than what is being used, if boiler is sufficiently full to allow of such adjustment, and then recuperate when engine is not using steam.

To make clear the evil results of the careless habit referred to, of supplying *more* than a proper equivalent of water at such times, we will take for illustration an engine with 145 pounds boiler pressure, pulling a train at a speed of twenty miles per hour, and using 400 pounds of water per mile. The fire must be kept suffi-

ciently hot to convert 400 pounds of water in the boiler into steam every three minutes, or 133 pounds every minute, if injector supplies boiler with an amount of water exactly equivalent to what is being used as steam. If careless adjustment of injector allows it to force 500 pounds of water into the boiler per mile run, or 166 pounds per minute, we will then have a surplus of thirty-three pounds of water entering the boiler each minute above what is being converted into steam and used.

This amount of water would hardly be noticeable in the glass at first, as, in a minute, it would increase the column of water there only about one-eighth of an inch. But it affects the coal pile. Each pound of this surplus water on entering the boiler absorbs sufficient heat to raise its temperature to that of the water in the boiler, 365°, which requires 337 heat-units per pound. The thirty-three pounds will absorb (33 x 337=) 11,121 heat-units. So in order to keep up steam we must force the fire to the greater intensity necessary to communicate over 11,000 units of heat more per minute to the water in the boiler than if only the proper equivalent had been supplied.

The loss results from forcing the fire to

furnish this additional amount of heat at a time when it is already taxed heavily to furnish heat sufficient for the formation of steam being used.

The opinion prevails among some engineers that it is best to keep the boiler as full of water as possible, and avoid priming, in order to have the engine steam freely. In short, that engines steam better with full boiler of water, or say full glass of water, than with it half or one-third full. When asked to give a reason for their opinion, they will say that the temperature of a large body of heated water is less affected by the injection of colder water than the temperature of a small body of heated water would be, therefore an engine will steam better with full boiler.

Falsehood, we are told, is never so deceiving as when accompanied by truth, and in the foregoing proposition we find truth in bad company.

Having become acquainted with the process of the formation of steam, we know that each pound of water in a boiler requires just so many units of heat transmitted to it to convert it into steam, regardless of whether it be a pound of a

large or a small body of water. Indeed, we know that a bubble of steam in forming must cope with the weight of the water above it. This being an established fact, the claim that the same amount of heat imparted to a large body of heated water will make more steam than if imparted to a small body of heated water, we readily see is a fallacy and without foundation. In practice, all that affects the steaming of an engine, so far as boiler-feeding is concerned, is, *not* how much water is in the boiler, but *how much* and *when* water is fed to the boiler.

Engineers who practice keeping their boilers as full of water as they can, and those who try to keep the water-level at as near one point in the boiler, or glass, as possible (some have boasted that a string could be tied around their glass at a certain point and the water would always be close to it), do not utilize the advantages that are offered to economize in fuel by the heat-storing quality of water. Such practices are all right in stationary engineering, where the work is constant, but in locomotive engineering, where the work required is constantly fluctuating between the maximum power

of the engine and no work at all, they are full of evil results to the coal pile.

An engineer abreast with his profession, and understanding that a boiler full of water under high steam pressure represents an immense store of heat, which, as his locomotive is a heat-engine, is a capital stock to start with, aims to always *start* with the boiler as full of water as he properly can, but does not aim to *keep* the boiler full, or the water-level at one point, but aims to draw upon his store of heat as far as is practicable to cause his engine to economically perform its work.

When steam pressure lags while engine is running and using steam, the injector should be shut off, when safe and proper, until the desired pressure has been regained, rather than resort to forcing the fire to regain the lost pressure with injector on.

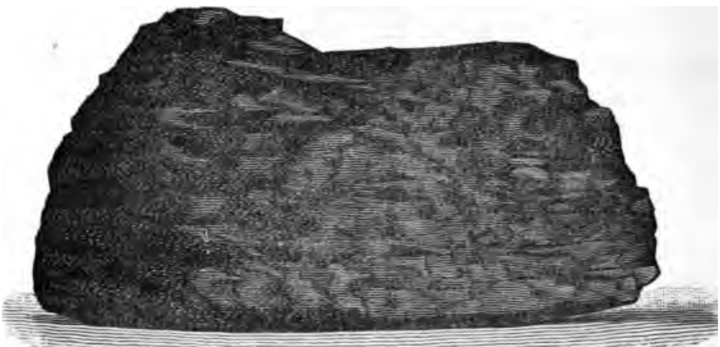
The waste of fuel resulting from steam blowing off, or popping, is very great, and should be carefully guarded against. By an actual test on a locomotive blowing off steam for four consecutive minutes for the purpose of the test, it was practically demonstrated that six cubic feet of water, or 336 pounds, was converted into steam

and wasted. This was at the rate of eighty-four pounds of water per minute, or $1\frac{2}{5}$ pounds per second. In ordinary locomotive practice six pounds of water are converted into steam per pound of coal burnt, so the amount of coal wasted in the four minutes was fifty-six pounds, or fourteen pounds per minute, or a quarter of a pound per second. The size of a lump of coal of this weight is shown in engravings opposite. Let us imagine a lump of coal of this size flying out of the safety-valve every second the pop goes off and we have a fair idea of the waste of coal resulting.

Knowing this, and understanding the advantages of stored heat in the boiler, no *engineer* will allow any surplus heat to be thus wasted if there is room to store it in the boiler.

When it is impracticable to put any more water in the boiler, blowing off may be prevented by opening the tank valve and injector throttle and allowing the surplus steam to escape into the tank, where its heat will be absorbed by the water there and saved.

In doing this, the tank valve *must be open*, and although the throttle may be opened full, it must be opened grad-



The above engravings give two views, actual size, of a lump of coal weighing ¼ pound.

ually, or the hose may be blown off or bursted.

It is also necessary to guard against getting the tank-water too hot for the injector to use, but, with most of the injectors in general use, this is not likely to occur. The Sellers (improved 1887), Friedman, and Monitor injectors will all work properly with the tank-water heated to over 110°, or unpleasantly warm for the hand.

Water so heated requires just so much less heat imparted to it in the boiler to convert it into steam.

Care must be taken not to fill the boiler so full of water that the steam will carry water over into the cylinders when engine starts. When a boiler is too full of water the space intended for steam room is lessened, which limits the volume of steam that may be formed. When the throttle is opened and a large proportion of this volume of steam escapes from the boiler the pressure on the surface of the water is suddenly reduced, and violent boiling occurs, throwing spray into the steam, which carries it to the cylinders, where it performs mischievous work, not only by washing the lubricating oil from the rub-

bing surfaces of valves and cylinders, but it absorbs heat from the steam it is mingled with and thus lessens its energy, even converting some of it into water. Danger to the engine also lurks in water carried to the cylinders. Water, which yields so freely to the hand plunged into it, is almost absolutely incompressible. Great force may be brought to bear upon it, but, sooner than shrink, it will ooze through the pores of the metal vessel which contains it, and spread like a dew on the surface.* Many shattered cylinder-heads have borne evidence to the incompressible nature of water.

To avoid the opposite extreme, the water-level should never be allowed to fall below a good fair margin for safety. The best results will follow a medium between extremes. The boiler should never be filled so full of water as to entirely fill the glass, unless the engineer knows from experience that the engine will work with that quantity without priming. Generally, within two inches of the top, and three inches of the bottom of the glass will be the proper limits of the water-line.

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* Professor Tyndall.

All good things result disadvantageously when carried too far, and it is the duty of the steam-engineer to take into consideration every influence that is exerted during the operation of producing heat and converting its force into work, and endeavor to strike a happy medium between the evils of extremes, always remembering that in operating a locomotive he deals with natural forces which are agents of usefulness or destruction only as they are curbed and mastered, and that his duty is to utilize every force at his command and every circumstance of daily practice to enable him to operate his engine with economy and success.

Instructions for Boiler Feeding.

14. Every opportunity must be improved to absorb and store in the boiler as much heat as possible when engine is not working, by filling the boiler with water as full as it properly may be, care being taken to maintain temperature of boiler and steam pressure by hot fire or slight application of blower.

15. In starting trains, and in all emergencies where an engine is forced to unusually hard work, the injector must be left off as long as it properly may be, or until the emergency of forced work is passed.

16. Surplus steam must not be permitted to blow off through the safety-valve if there is water-room to store it in the boiler, or if the temperature of the tank-water may be properly increased.

17. At terminus of trips the remaining heat of the fire must be carefully utilized in storing the boiler with hot water to assist in economical firing up. Injectors must not be used after the fire has been withdrawn from the fire-box.

USE OF STEAM.

USE OF STEAM.

In this chapter we will consider the proper and economical use of steam, which depends upon two circumstances: the excellence of the engine and the care of the engineer.

"The locomotive engine which reaches nearest perfection is one which performs the greatest amount of work at the least cost for fuel; * * * the nearest approach to perfection in an engineer is the man who can work the engine so as to develop its best capabilities at the least cost."*

This is true, and in the following pages we will discuss the matter of the economical use of steam by locomotives, as it is effected by the engineer.

For many years the best engineering talent in the world has been devoted to perfecting the steam-engine, in order to make it do more work with the fuel used,

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* Mr. Angus Sinclair, "*Locomotive Engine Running and Management.*"

and the locomotive has received its share of attention.

Modern locomotives are so constructed as to utilize in the greatest degree possible, with the knowledge of the present time, the heat of the fire.

So, the first requisite for the economical use of steam, namely, an excellent engine, is met and provided for; and it remains for the engineers of those engines to complete the necessary requirements by careful and intelligent work.

That is all that is necessary; not extra work, but careful work, guided by a correct and intelligent understanding of *the proper way*, and its good results.

In the early days of steam-engines low pressure steam was used, but it necessitated allowing the steam to follow the piston at boiler pressure nearly or quite the entire length of the stroke, which caused extravagant use of fuel.

With higher pressure it was found that more work could be done with a great deal less steam by cutting it off early in the stroke and allowing it to spend its expansive force in pushing the piston the remainder of the stroke, than could be done formerly with several times the

expenditure of steam. Boilers were strengthened and machinery improved to utilize this great advantage offered by the expansive force of steam.

Let us make clear to ourselves this advantage and its attendant results.

In the last chapter, we had two cases of a pound of water converted into steam; in the first case to atmospheric pressure, and in the second case to 145 pounds pressure.

In the first case the steam filled the tube of one square foot area to a height of twenty-seven feet, and thus formed a volume of twenty-seven cubic feet.

In the second case it filled the same tube to a height of only 2¾ feet. In this case the same amount of steam is compressed into a space one-ninth that of the steam of atmospheric pressure.

Being compressed, it is exactly like a compressed spring, and capable, if permitted, of expanding in volume, until under atmospheric pressure only, it occupies the space of steam of that pressure, or nine times as great as at its present pressure. But in expanding it can perform work and give up the potential energy with which it is possessed.

As it took 1,193 heat-units to confer upon our pound of steam the energy due to steam of 145 pounds pressure, the economy with which it is used depends upon how much of that heat we can cause the steam to convert into work in the cylinder of our engine.

Of all the heat we have imparted to the water and steam, only that given up by the fall of high pressure steam to low pressure steam is available for use by the locomotive.

As that is but a small fraction of the whole, it is apparent that our best efforts should be exercised to utilize to the fullest possible extent the energy of our steam before we allow it to escape through the exhaust.

So it is that, under ordinary circumstances, the higher the temperature and pressure of the steam as it enters the cylinder, and the lower its temperature and pressure when it leaves, the greater is the amount of heat converted into work.

This can only be accomplished by using the steam expansively; admitting it to the cylinder at high pressure, and cutting it off early in the stroke, and thus cause it to spend its expansive force in pushing the

piston the remainder of the stroke, when it will be exhausted at low pressure, having yielded up a part of its heat and energy.

With locomotives starting trains, it is not possible to use to any great extent this expansive force of steam, but in forcing trains into speed, and pulling them over the road, it offers the greatest opportunity we have to economize in the use of steam and fuel.

While performing such work, the engine should be run with throttle wide open, allowing the steam to enter the cylinders as near boiler pressure as possible, and then cut it off as early in the stroke as possible consistent with the work to be done.

The practice of running with reverse-lever in notches where the valves are caused to cut off at eight, ten, and twelve inches of the stroke, and then regulating the power the engine must develop by the *throttle*, by increasing or decreasing the pressure of the steam in the cylinders, is *very* wasteful and wrong, and a practice to be avoided as much as circumstances will possibly permit.

A slight opening of the throttle *wire-draws* the steam, and causes it to enter the cylinders at a lower pressure than that of

the boiler, and thus deprives it in a great measure of the potential energy we have invested it with; and its ability to perform work in the cylinders is lessened and *degraded.*

Degraded exactly applies to steam thus robbed of its rightful degree of energy, and the cause, whether it be the fault of the engine or the careless practice of the engineer, requires immediate correction.

In order to clearly and correctly understand the evils and waste of throttling and wire-drawing steam, let us take three examples of the performance of steam in a locomotive's cylinders while cutting off at six, eight, and ten inches of the stroke respectively, in each case performing the same amount of work, and notice the difference in the amount of steam and heat consumed in its performance in the several examples.

First Example.

An engine with cylinders 18 x 24, and 145 pounds effective boiler pressure, admits steam of 140 pounds pressure to the cylinders until cut off at six inches of the stroke.

We will note the performance of the steam in one cylinder, which will illustrate what takes place in both.

The piston being eighteen inches in diameter, has an area of 254$\frac{3}{4}$ square inches. When it has moved six inches of the stroke, it has admitted nearly nine-tenths (.8855) of a cubic foot of steam, which at this pressure weighs three-tenths (.3129) of a pound.

Steam of this pressure contains 1,192 heat-units per pound. So the quantity of steam we have admitted to the cylinder contains 373 units of heat.*

Steam is cut off from the cylinder by the valve at this point, and the steam imprisoned in the cylinder overcomes the resistance of the piston, and in forcing it to the end of the stroke expands to four times its volume; and decreasing in pressure and temperature as it expands, is, at nearly the end of the stroke, exhausted at a pressure of thirty-five pounds.

The average or mean pressure upon the piston during the stroke was seventy-seven pounds per square inch.

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* No account is taken of the clearance space at each end of cylinder in these examples.

Second Example

With same engine, and cylinder, and pressure in the boiler, we admit steam to eight inches of the stroke before cutting it off; and as we only wish the engine to perform the same amount of work as in the first example, we must throttle the steam, and reduce its pressure as it enters the cylinder to 117 pounds per square inch.

This pressure will, when cut off at eight inches, develop seventy-seven pounds mean pressure on the piston during the stroke. In allowing the steam to follow the piston eight inches of its stroke we admit 1.18 cubic feet of steam, which contain at this pressure 424 units of heat; fifty-one units more than was contained in our steam during the first example, yet the work done is the same.

This is a clear waste of fifty-one units of heat for each stroke of each piston; and the steam in expanding but three times its volume gives up less of its heat and escapes through the exhaust at thirty-nine pounds pressure. We have measured the loss for one stroke of one piston, let us measure the loss for a complete revolution of the

driving-wheels, during which each piston would make two strokes—four in all; so four times fifty-one, or 204 units of heat, is the loss for one revolution.

If our driving-wheels are sixty-nine inches in diameter they will revolve 292 times in running one mile.

As we are wasting 204 heat-units at each revolution, we will waste (292 x 204 =) 59,568 units in running one mile under the conditions of this example.

THIRD EXAMPLE.

We will in this case allow the steam to follow the piston ten inches of the stroke before cutting off, and we will throttle the steam still more than in the last example, so that the engine shall perform the same amount of work.

The steam is throttled to 103 pounds pressure, which at this cut-off will effect a mean pressure of seventy-seven pounds. At this cut-off we admit 1.47 cubic feet of steam, which contain at this pressure 471 units of heat, forty-seven units more than in the last example, and ninety-eight more than in the first example; yet the work done in each case has been the same.

In this last example steam would expand

but 2.4 times, and would escape at forty-three pounds pressure.

An engine run in this way one mile would waste 114,464 units of heat as compared with the first example.

This amount of heat would be generated by the perfect combustion of eight pounds of coal; but in practice we are able to absorb, for steam-producing, only about one-half of the heat of perfect combustion; so it would require sixteen pounds of coal to supply the heat wasted in running one mile under the conditions of the last example, as compared with first example, amounting to 1,600 pounds wasted in a trip of 100 miles.

While not taking into consideration all the events of steam in a cylinder during a stroke of the piston in these examples, one of which has a tendency to counteract the advantages of high initial pressure and early cut-off, yet the examples give a fair illustration of the economy resulting from running a locomotive with full throttle, and as early a cut-off as possible consistent with the work to be done, and the waste of heat, steam, and fuel attending the vicious practice of running with light throttle and late cut-off.

Cylinder condensation limits the degree to which the expansive force of steam may economically be used, and it is present in a measure in all cylinders of engines running with early cut-off.

It is caused by the metal of the cylinders absorbing, to some extent, heat from the steam and conducting it away. It is a source of loss, and increases generally as the ratio of expansion is increased, and finally limits the economical use of that quality of steam.

But this limit is seldom reached in locomotive operating. "Steam is never expanded too far with locomotives having the link-motion, and fairly well protected cylinders; and the advice will generally be accepted as sound, to make the ratio of expansion as great as possible.

"The transatlantic steamers that have been operated most economically, use from seven to eight expansions with compound engines and steam-jacketed cylinders, and many engineers believe that even this expansion is far too limited.

"This would probably be too much for locomotives, but there are data indicating that nothing short of five expansions is

likely to cause waste of heat unless the cylinders are very badly covered." *

In locomotive practice the only limit is the *work to be done*, and the advantages of thus utilizing to the greatest possible degree this expansive quality of steam are not confined to the saving of heat in the quantity of steam used; there are other important advantages which more than counterbalance all evils of cylinder condensation.

In our three examples steam was exhausted at thirty-five, thirty-nine, and forty-three pounds respectively, increasing in pressure as the ratio of expansion decreased.

Contracted exhaust nozzles being necessary to free-steaming locomotives, we here gain a four-fold advantage by using steam of high initial pressure with early cut-off; there is less steam to be exhausted; being at a lower pressure, it is more easily exhausted, and causes less back pressure in the cylinders. Escaping from the nozzles at a lower pressure, the force of the exhaust is less, and produces a milder draft

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* Mr. Angus Sinclair, *National Car and Locomotive Builder*, August, 1887.

through the fire, burning less coal, and allowing the heat and products of combustion to pass from the fire-box and through the flues with a slower motion, and therefore remain longer in contact with the heating surface; which, as the transmission of heat is *a matter of time,* allows more of the heat to be imparted to and absorbed by the water in the boiler.

The indicator is an instrument which, when applied to the cylinder of an engine, indicates by tracing lines on a card the action of the steam in the cylinder as correctly as the steam-gauge indicates the pressure in the boiler.

We have had three examples, theoretically illustrating the saving effected by high pressure and early cut-off, as compared with low pressure and late cut-off.

We noted the amount of heat wasted at every stroke of the pistons, and every revolution of the driving-wheels, and were impressed with the great waste of coal which would result, by the latter course, in a trip of 100 miles. Let us allow the indicator to give us two examples from actual practice by diagrams taken from the cylinder of an engine.

They furnish a good and truthful illustra-

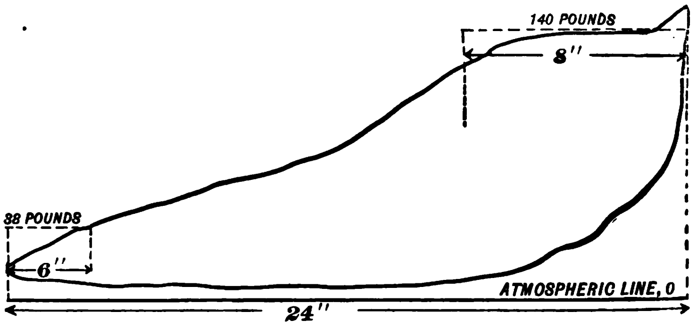
tion, from practice, of the waste attending the use of throttled steam and late cut-off, and the saving effected by running with full throttle and early cut-off.

In our late examples we measured the steam used at each stroke, and the amount of heat that steam contained.

In the examples given us by the indicator we will measure the amount of steam used in pounds weight. One pound of water makes one pound by weight of steam, and thus we will measure the number of pounds of steam or water, that is used by the engine in performing its work under the two different conditions named.

As we know that it requires one pound of coal to change six pounds of water into steam of 145 pounds pressure, in ordinary locomotive practice, we can arrive at nearly a correct measurement of the economy of early cut-off.

DIAGRAM NO. 1.—FULL THROTTLE.



In this case the boiler pressure was 145 pounds; the throttle wide open, admitting steam of 140 pounds pressure to the cylinder.

The cut-off took place at eight inches of the stroke, the steam was exhausted at thirty-eight pounds pressure, at eighteen inches of the stroke, developing a mean effective pressure of seventy pounds, 186 horse-power, at a speed of twenty-eight miles per hour.

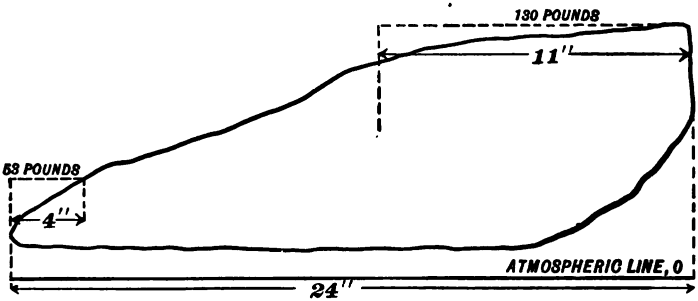
The cylinder was 19 x 24, an area of 283.5 square inches. The valve opened the exhaust port at eighteen inches of the stroke with the steam at thirty-eight pounds pressure.

At this point there was 2.95 cubic feet of steam in the cylinder, weighing, at this

pressure, .374 of a pound, which is the weight of steam or water used in this stroke. In one revolution of the driving-wheels, four times this amount, or one and a half (1.5) pounds of water would be used.

The driving-wheels are sixty-three inches in diameter, and revolve 320 times in running one mile; therefore, we would use (320 x 1.5 =) 480 pounds of water per mile.

DIAGRAM NO. 2.—STEAM THROTTLED.



In this case the boiler pressure was the same, but steam was throttled to 130 pounds and allowed to follow the piston eleven inches of the stroke before cut off.

It was exhausted at twenty inches of the stroke at a pressure of fifty-three pounds, developing a mean pressure of seventy-five

pounds, 188 horse-power, at a speed of thirty miles per hour.

At the point of exhaust we have 3.28 cubic feet of steam, which at fifty-three pounds pressure weighs .526 of a pound, which is the amount of steam or water used in this stroke.

At each revolution (4 x .526 =) 2.1 pounds of water were used, and (320 x 2.1 =) 672 pounds per mile.

While the work done by the later cut-off was slightly greater than with the early cut-off, yet it was done at an extravagant waste of fuel and water, as we shall see by comparing the two performances.

By the early cut-off 480 pounds o. water were used per mile run. By the late cut-off 672 pounds of water were used per mile run.

A difference of 192 pounds of water per mile; which amount required thirty-two pounds of coal to convert it into steam of boiler pressure

So the small excess of work was performed at an expense of thirty-two pounds of coal per mile, amounting to 1½ tons in a trip of 100 miles

It may appear that this is an extreme case, but there are many locomotives being

run with a near approach to the extravagant waste indicated by diagram No. 2, and it results from some engineers having wrong ideas of the effects of pulling the throttle wide open.

Many engineers habitually run their engines with the throttle nearly closed, or only partly open; and if it is necessary for the engine to perform harder work than it will do with short cut-off and light throttle, they advance the reverse-lever a notch or two and increase the length of admission of steam to the cylinders. Then the increased work is performed with nearly a double consumption of coal.

The engine could be caused to perform nearly the same amount of work by leaving the reverse-lever alone and pulling the throttle wide open.

One engineer "don't believe in pulling the throttle wide open, because it puts too much weight on the top of the valves;" another "fears it is too much strain on the valve-stems;" another "believes the valve-seats will wear hollow, and need facing oftener than with a light throttle;" another imagines "the boiler will prime with a full throttle;" another "believes that he can regulate the speed better with the throt-

tle;" and yet others run with light throttle and late cut-off "because they have always been in the habit of doing so, and the men they fired for did so, too."

This is false reasoning, and the throttle should come *wide open.* It is made strong enough so that it will not break, or become disarranged or injured by being freely used.

The valves are strong enough to bear and move under the weight of the boiler pressure on their tops. The valve-stems are strong enough to stand the strain; and if they break, or the valve-seats become hollowed and need facing—the engineer will not be charged with the expense.

If the boiler primes, it is because it is too full of water, not because the throttle is open.

There are no evil effects to follow the free admission of steam to the cylinders at as near the boiler pressure as possible, and locomotives should perform their work with the throttle full open, and the valves cutting off as early in the stroke as possible consistent with the work the engine must perform.

Of course this applies only after trains have been started, and are being either

forced into speed or pulled over the road.

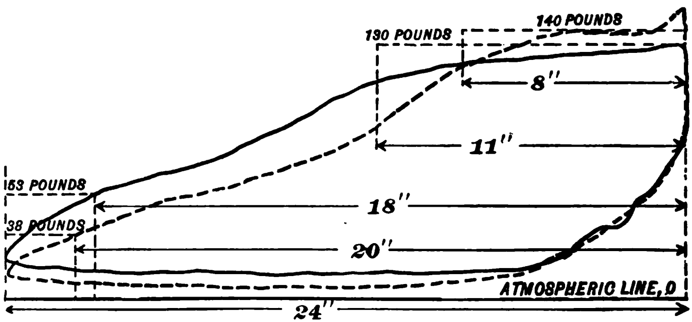
In starting trains it is necessary to work the engine full stroke, and throttle the steam so as to prevent slipping of driving-wheels; which is not only liable to injure the engine by pulling off pins and breaking rods, but affects the fire injuriously and causes waste of fuel in many ways.

Figure No. 1 presents diagrams Nos. 1 and 2 together, so that their difference may be noted.

The dotted lines form diagram No. 1.

The plain black lines form diagram No. 2.

FIGURE No. 1.



The near approach of the bottom, or back pressure line of diagram No. 1 to the atmospheric line, indicates less back pressure for early cut-off than is the

case with diagram No. 2, with late cut-off.

Some engineers practice forcing their trains into speed from stops in as short a possible distance and time as they can. The practice is responsible for much unnecessary waste of fuel. Often a difference of 100 pounds of coal in running the first mile from a station depends upon the engineer using careful judgment in working his engine during the hard task of work it is then engaged in, and guarding against working it harder than is necessary to force the train into speed in the required time. It is an extravagant and dangerous practice to make up time pulling out of and running into stopping places.

The discussion of this subject may now be closed by summarizing its several points. We have become familiar with heat, its cause, nature, and power of performing work. We are familiar with the nature of combustion, and with the conditions necessary to secure the best results and greatest heat from burning fuel. We are acquainted with the valuable qualities possessed by water of absorbing and storing heat, and of the great advantages

they offer to economize in fuel. We are also acquainted with steam, its formation, and ability to perform work through the means of an engine, and with the manner of its proper and economical use, and with the waste and evil results attending its improper use, which we have seen illustrated theoretically and demonstrated practically.

It is the duty of all connected with the operating of locomotives to bear these points in mind, and carry them out in practice, being assured that only by the daily practice that does not weary in well-doing, can great results be accomplished, or success attained in any calling.

INSTRUCTIONS—USE OF STEAM.

18. In starting, steam must be used so as to avoid jerking trains and slipping driving-wheels. Slipping must be prevented by reduction of steam pressure in cylinders, or use of sand.

19. In pulling trains, when consistent with the work to be done, engines must be run with the throttle full open, admitting the pressure of the boiler to the cylinders, and with valves cutting off steam as early in the stroke as possible consistently with the work required.

FRICTION AND LUBRICATION.

Friction and Lubrication.

Friction is a resisting force which always acts to prevent or retard the motion of bodies in contact. It retards the motion of machinery, and by the friction of journals turning against their bearings, by the friction of the wheels rolling upon the rails, and of their flanges against the rails, by the friction of the air against the exposed surfaces of engines and cars in motion, the speed of trains is retarded, and finally limited.

The work of friction, therefore, is a matter of importance to engineers, for the reasons that it absorbs and wastes a seriously large amount of the available energy of locomotives, and converts all energy so diverted from useful work into *heat*, which may give rise to inconvenience and delay, and injury, and even destruction of moving parts.

In all cases the action of friction in the machinery and rubbing parts of an engine results in *increase of the effort required to drive it*, so, not only to prevent wearing

and injury to the surfaces in contact, but to be economical in the use of power, friction must always be reduced to the lowest possible degree. This devolves upon the engineer, and may be effected by a judicious use of the lubricating oils with which his engine is supplied.

The objects of lubrication are to reduce friction and prevent the development of heat, and are accomplished by interposing between the smooth rubbing surfaces of machinery, and journals and bearings, a film of oil of sufficient "body" to keep the surfaces between which it is interposed from coming together, so that the rubbing parts nowhere, and at no time, come into metallic contact.

The use of more oil than is necessary to effect this purpose is an unnecessary waste and should be avoided.

To do which, the first condition necessary to observe is the *temperature* of the oil to be applied. * It should not be greater than is necessary to allow the oil to flow freely from the spout of the oiling-can, which it will generally do at a tem-

* These remarks apply to the use of engine-oil, not to the use of cylinder-oil.

perature of 80°, or 20° below blood heat, which is 100°. It should not be applied hotter than this for several reasons, one of which is: it will be so thin, especially in summer, or when applied to hot surfaces, that it will not adhere sufficiently to the surfaces it is interposed between so as to prevent friction, but will, under heavy pressures, be forced in part from between them. Another reason is: it will run off from the tops of driving-boxes and engine-trucks, and from surfaces it is intended to lubricate, faster than if it was less warm and thin. "The greater the consistency of the lubricant, other things being equal, the greater its endurance and economy." *

Temperature affects the lubricating quality of oil, and the friction of rubbing surfaces very greatly. Friction increases rapidly when the temperature of the surfaces in contact is greater than 90° In this we find another reason why oil should not be applied to the surfaces it is intended to lubricate when it is warmer than about 80°, because one duty of the lubricant is to absorb and carry off the heat generated by

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* Professor Thurston—"*Friction and Lost Work.*"

friction, and if the lubricant be warmer than the temperature named it must fail in this duty, and if it be hotter than 90° it adds undesirable heat to the surfaces it comes in contact with.

From all of which it must be plain that the common practice of carrying oil-cans close against the boiler-head in warm weather, where the oil they contain becomes heated to the temperature of 140° or 160°, and then using this hot oil for the purpose of lubrication, is not only wasteful of oil, but a bad practice generally, and liable to be (and often is) attended by the inconvenience and delay due to heated journals or other parts, and the loss of power connected with it. One "hot-box" on engine or train noticeably affects the coal pile.

When the shelf attached to the boiler-head is the only place provided for carrying oiling-cans, the temperature of the oil should be cooled to about 80° before being used, by dipping the can in water.

In using engine-oil in cold weather that will not flow freely, it is best to dilute it sufficiently with kerosene in order to make it of the proper consistency rather than heat it to a high temperature. When used

heated, instead of diluted sufficiently, its heat is absorbed immediately it touches the cold metal surface it is applied to, and it congeals and takes the form of grease, and is then not so good a lubricant by far as when in the liquid state. Indeed, to be a proper lubricant it must be in the liquid state, when not, friction exists between the sticky layers of grease adhering to the metal surfaces and passing over one another. This friction, which is called "*the friction of fluids*," acts nearly the same as the friction of solids, and retards motion, making greater power necessary to run the engine.

Generally in mills and shops the engine and machinery are started running several minutes before the time to commence work in order to get everything "warmed up." This is made necessary by the retarding force of the friction of the lubricating material lying between the rubbing surfaces of the machinery in a congealed state.

By the way trains drag for the next few miles after a delay of thirty minutes in cold weather, enginemen are made painfully aware of the action of friction in the congealed oil lubricating the journals

of the engine and cars constituting the train.

For this reason it is best to use only signal-oil in freezing weather to lubricate the valve-gear, except the eccentrics and link-blocks, and the heavy valve or cylinder oil should only be used in steam-cylinders or on hot surfaces.

Oiling should be invariably attended to before the commencement of the trip. Every movable part and every oil-hole should receive its share of attention and oil. Oil-holes stopped up should be promptly and thoroughly cleaned.

Driving-boxes, wedges, engine-trucks, and the valve-gear, except eccentrics and link-blocks, generally need oiling only once every fifty or sixty miles. The eccentrics (when not equipped with cups) link-blocks, guides, piston-rods, and front end of main-rod (with open cups), need attention about every thirty miles. Three pints of "engine-oil" per run of 100 miles is generally sufficient. A squirt-can should be used to oil the valve-gear (except eccentrics and link-blocks) and regular oiling-can to oil all other parts. Oil-cans with leaking bottoms and broken spouts should not be used while in that condi-

tion, but should be repaired as soon as possible.

All rod-cups should be filled before starting out on any trip, and covers secured. Main-rod cups should be adjusted to feed over half a cupful of oil per trip of 100 miles, and side-rod cups over half a cupful per trip of 200 miles.

Guide-cups should be kept covered and clean, and should be adjusted to feed only an amount of oil necessary to keep the rubbing surface of guides and cross-heads well lubricated, judging from their appearance. The feed should be closed when delayed any considerable time at stations, and at the end of each trip.

Only the oil supplied for that purpose should be used for lubricating valves and cylinders, and no more of it than is necessary. With sight-feed lubricators and cylinders 16 x 24 to 18 x 24, from two to four drops of oil per minute is sufficient for proper lubrication; with larger cylinders, five or six drops per minute may be necessary. More than this is an unnecessary waste. On engines where steam must be shut off to oil the valves and cylinders, an amount of oil equal to two tablespoonfuls

for each side, supplied every fifteen or twenty miles, is sufficient.

Only an amount of oil that can *adhere* to the internal rubbing surfaces is of any use; all supplied in excess of that amount is worse than wasted, for it is carried from the cylinders in the exhaust steam, much of it adhering to the exhaust pipes and nozzles, and forming a gum which acts mischievously in choking the free escape of the exhaust, which causes back-pressure in the cylinders.

It is very important, in studying the economical use of power, to study also the proper and economical use of lubricating oils. The former depends greatly upon the latter, and every movable part should be kept well lubricated with oil, the temperature and consistency of which has been carefully prepared to suit the conditions of its actual use.

Much depending, then, upon proper lubrication, "oiling around" should never be done hurriedly, but carefully and deliberately, looking well to the general condition of the engine, the temperature of journals, pins, eccentrics, and the appearance of lubricated surfaces.